

ASTROPARTICLE PHYSICS WITH AMS02

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Abstract

The Alpha Magnetic Spectrometer (AMS02) experiment will be installed in 2009 on the International Space Station (ISS) for an operational period of at least three years. The purpose of AMS02 experiment is to perform accurate, high statistics, long duration measurements in space of charged cosmic rays in rigidity range from 1 GV to 3 TV and of high energy photons up to few hundred of GeV. In this work we will discuss the experimental details and the physics capabilities of AMS02 on ISS.

1 Introduction

In June 1998 a reduced version of the Alpha Magnetic Spectrometer (AMS01) experiment has successfully flown for 10 days on Space Shuttle Discovery (STS-91). This mission has provided valuable information on detector performance in actual space conditions and interesting cosmic ray data. The detector layout, performance and the physics results of AMS01 during STS-91 mission are described in detail elsewhere (Aguilar et al., 2002).

The AMS02 is a multi purpose detector aiming to study, with unprecedented sensitivity, cosmic antimatter, the indirect search of dark matter constituents and perform high accuracy and high statistics charged cosmic ray spectra up to TeV region. AMS02 will also measure the high energy gamma rays up to few hundred GeV with good source pointing capability.

2 AMS02 Experiment and Detector Performance

In order to achieve physics goals, the detector requirements include large acceptance ($\sim 0.5 \text{ m}^2 \cdot \text{sr}$), accurate particle identification and rigidity ($\frac{p}{Z}$), energy, charge measurements, as well as good e/p separation and the system redundancy. Fig.1 shows an exploded view of AMS02 experiment together with tracker rigidity resolution and dE/dX performance for nuclei charge determination.

In the following the AMS02 sub-detectors will be briefly described from the upper part of the experiment.

- The Transition Radiation Detector (TRD) is designed to suppress the proton signal with a rejection factor against positrons of 10^3 - 10^2 in the energy range from 10-300 GeV. The TRD consists in 20 layers of 6 mm diameter straw tubes alternating with fleece radiators. The straw-tubes are filled with a 80%/20% mixture of Xe/ CO_2 at 1 bar. Combined with the Electromagnetic CALorimeter (ECAL) performance, an overall e^+ /p rejection factor of $\sim 10^6$ at 90 % of e^+ efficiency will be achieved.
- The Time of Flight (ToF) system consists of four planes of plastic scintillator placed at both ends of superconducting magnet. Lightguides were designed to minimize the angles between local magnetic field and PMT axis to optimize their response. The ToF is designed to provide fast trigger to the experiment, measurement of time of flight of the particles traversing the detector with up/down separation and dE/dX measurements. The $\Delta\beta/\beta$ is 3% for protons and the estimation on absolute particle charge can be done up to $Z=20$. The beam tested overall time resolution is 160 ps for protons and better for heavier cosmic ray nuclei.
- The SuperConducting Magnet (SCM) bore has a diameter of 1.1 m in which the silicon tracker is mounted. The SCM consists of two dipole and two sets of smaller racetrack coils with a total cold mass of

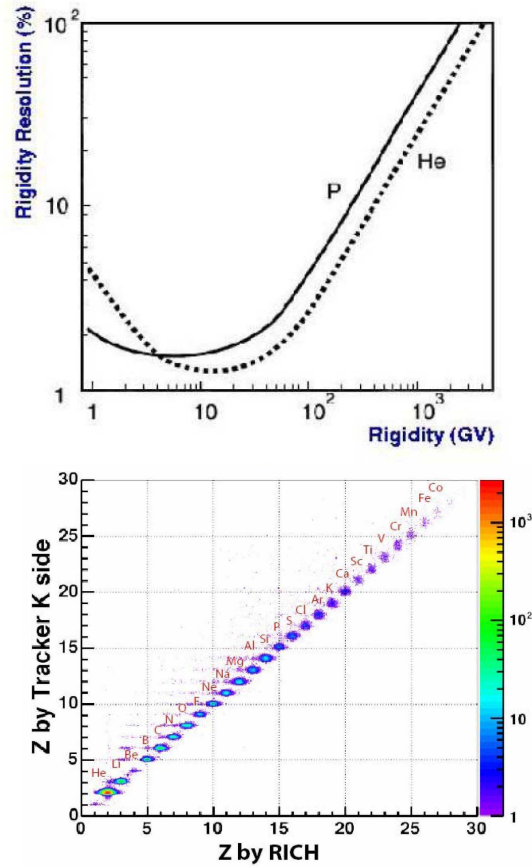
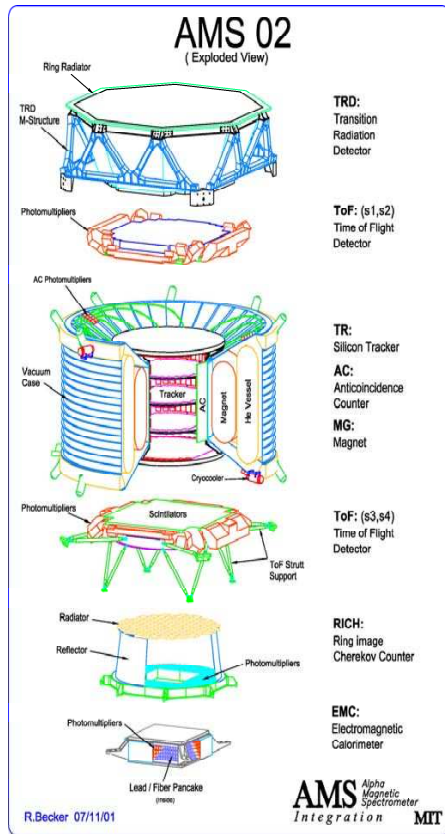


Figure 1: The AMS02 exploded view (Left). The silicon tracker rigidity resolution for p and He(upper right). The nuclei separation with dE/dX measured both by silicon tracker and ring imaging Cherenkov detector (lower right).

about 2300 kg. The racetrack coils are designed to increase the overall dipole field, to minimize the stray dipole field outside the magnet (max stray field at a radius of 3 m is 4 mT). It has a bending power of $B \cdot L^2 \sim 0.8 \text{ Tm}^2$. All coils are wound with high purity aluminum-stabilized niobium-titanium conductor. The magnet will be operated at a temperature of 1.8 K and cooled by 2500 l of superfluid helium, and it should be operational for three years without refilling.

- The Silicon Tracker of AMS02 is designed to perform high precision rigidity measurements, and to determine the sign and the absolute value of particle charge. The ST consists of 8 thin layers of double-sided, 300 μm thick, silicon microstrip detectors of lengths up to 60

cm. The ST has 0.3 % of total radiation length and 6.7 m^2 of active surface. The readout electronics is based on low noise, low power, high dynamic range VA64-HDR9 VLSI, circuitry. The charge determination capability combined with that of Ring Imaging Cherenkov (RICH) detector is given in Fig.1(Lower Right). In Fig. 1(Upper Right) an estimate of the AMS02 proton rigidity resolution (>5 hit track) for protons and helium is shown.

The tracker cooling system bases on two-phase mechanically pumped closed circuit in which cooling fluid (CO_2) runs by capillary forces. The fluid enter the tracker just under the boiling point to collect the heat and then outgoing fluid/vapor mixture is cooled on thermal radiator panels. The system dissipates 150 W.

- In AMS02, Ring Imaging Cherenkov Detector (RICH) provides additional velocity measurement with $\Delta\beta/\beta$ of 0.1% up to $Z=26$ and the isotopic separation is covered in the energy range from 0.5 GeV/n to 10 GeV/n for $A \leq 10$. The RICH is a proximity focusing device with a dual solid radiator at the top, an expansion volume at the center and a matrix of multipixelized photon readout cells at the bottom.
- Below RICH, the AMS02 includes a fine grained sampling Electromagnetic CALorimeter (ECAL, $16 X_0$ and 18 samplings) for 3-D imaging of shower development hence discrimination between hadronic and electromagnetic cascades. ECAL is a sampling device with a lead-scintillating fibers structure with 9 superlayers (X and Y views) each containing 11 grooved Pb foils interleaved with 10 scintillator fiber layers glued with epoxy resin. The design goal for ECAL is to provide precise ($dE/E < 5 \%$) e^- , e^+ and γ spectrum from 1 GeV to 1 TeV and good e/p discrimination ($O(10^3)$ for <500 GeV). The TRD+ECAL and ST combined e/p separation is $> 10^6$. Moreover, for gamma ray studies, ECAL acts as independent photon detector with an angular resolution of $\sim 1^\circ$.
- The star tracker system (AMICA) will give a precise measurement of the AMS02 observing direction with a few arc-sec accuracy.

In ASM02 there are a total of $\sim 300,000$ electronic channels delivering about 7 Gbit/s of raw data. The predicted total trigger rate varies from 200 to 2000 Hz. The DAQ electronics reduces the event size, through proper filtering, to the allocated downlink data rate of 2 Mbit/s.

All electronics and mechanical parts of AMS02 are tested for operation in vacuum, EMI/EMC compatibility, vibration and thermal cycles. The effect of total ionization dose (up to 6 Gy/year) on all critical components is extensively tested. The AMS02 weighs about 7 tons and has a power consumption of about 3 kW.

3 AMS02 Physics

3.1 Antimatter Search

The excess of baryonic matter over antimatter is characterized by the observed ratio $\eta = (n_B - n_{\bar{B}})/n_\gamma \cong 10^{-10}$. Over the time to evolve the initially symmetric universe into today's matter dominated one (baryogenesis), according to Andrei Sakharov (A. Sakharov, 1967), three principles should be fulfilled: non conservation of baryonic charge, breaking of C and CP invariance and the deviation from thermal equilibrium. Though there are several theories (Soni, 1997) suggest that the quantum effects allow universe to tunnel between vacua with different baryon number (B) values and this tunneling may occur at future supercollider energies (>10 TeV, the sphaleron mass), at present there is no experimental evidence that B is violated. Moreover the Belle and Babar experiments have looked into the violation parameter $\sin 2\beta$ ($=\sin 2\phi_1$) using $B^0 \rightarrow J/\Psi K^0$ channel (Daniel R. Marlow, 2003; S. Noguchi, 2003). Two independent experiments employ different detectors and analysis techniques but nonetheless yield results consistent with one another and with the Standard Model expectations based on measurements of other CKM matrix parameters. The results are $\sin 2\beta = 0.75 \pm 0.09 \pm 0.04$ (BaBar 56 fb^{-1}) and $\sin 2\phi_1 = 0.82 \pm 0.12 \pm 0.05$ (Belle 42 fb^{-1}).

There exist different inhomogeneous baryogenesis models, mostly based on assumptions that different sign of C(CP) breaking in different space points and moderate blow-up of regions with a definite sign of charge symmetry breaking. They predict matter and antimatter regions (Dolgov, 2002; Kirilova 2002) with antimatter structures like antigalactic clusters, antigalaxies situated between clusters of galaxies and antistar globular clusters providing signatures in $^3\bar{H}e$ and $^4\bar{H}e$ spectrums. Present antihelium/helium ratio limits and expected AMS02 sensitivity for three years on ISS are given in Fig.2(Left).

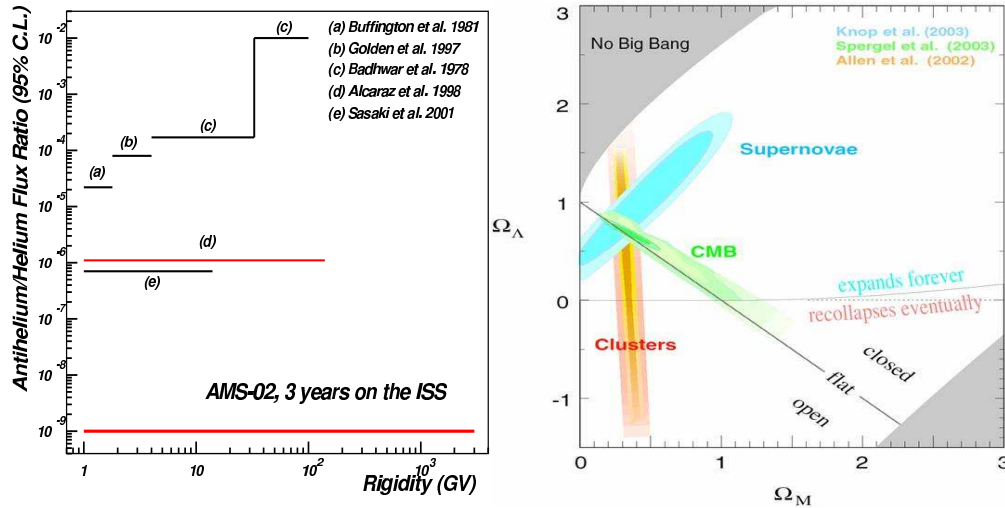


Figure 2: (Left): The $\frac{\bar{H}e}{He}$ flux ratio as a function of rigidity for present data and the expected AMS02 limit after three years on ISS. (Right): Ω_Λ - Ω_m plane; all data is converging for a flat and expanding Universe.

3.2 Dark Matter

At all scales (galaxies, clusters, superclusters...) the visible mass is not sufficient to explain the observed dynamical effects. As it can be seen from the Fig.2(Right) that in the Ω_Λ - Ω_m plane all the different measurements; SNIA brightness observations, Cosmic Microwave Background (CMB) anisotropies and optical measurements of clusters of galaxies, converge to a unique point. The universe is flat and will expand forever (Aldering, G., et al., 2004). In this picture universe is made of $\sim 72\%$ dark energy, $\sim 23\%$ (non-baryonic) darkmatter, $\sim 4\%$ baryons and $\sim 0.5\%$ neutrinos. Dark (negative potential) energy, permeating everywhere causes the increase on expansion speed and the gravity is not enough to hold constant the recession velocity.

The weakly interacting massive particles (WIMPs), postulated in minimal supersymmetric standard model (MSSM) and in other R-parity conserving supersymmetric models, are particularly attractive to explain dark matter's nature (Ellis & Ferstl & Olive, 2002). In this framework the lightest supersymmetric particle (LSP), stable neutralino, χ , a neutral scalar boson being also its own antiparticle, is the most quoted candidate. Indirect signals may be produced by annihilation of neutralinos inside the celestial bodies where χ 's have been captured and accumulated. The signals then emerge from $\chi\chi \rightarrow W^+, W^-, hadrons, b\bar{b} \rightarrow \gamma\gamma, e^+, \bar{p}, \bar{D}$ or $\chi\chi \rightarrow \gamma\gamma, Z_0\gamma$.

The AMS02 will be unique experiment detecting all annihilation prod-

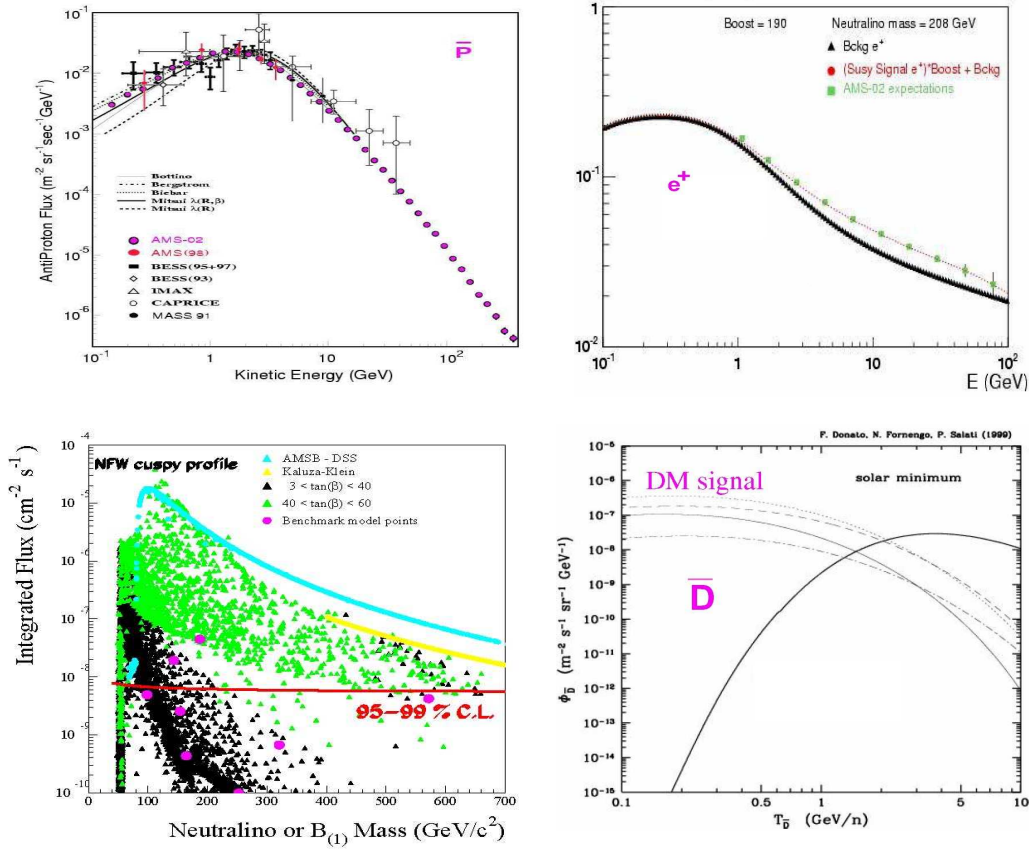


Figure 3: For different neutralino annihilation products detectable by AMS02. (UL): \bar{p} flux for present data and expected AMS02 accuracy. (LL): integrated γ flux from galactic center as a function of m_χ for a cuspy NFW dark matter halo profile (Jacholkowska et al., 2005). (UR): positron excess and AMS02 signal for $m_\chi=208\text{GeV}$. (LR): \bar{D} signal (dashed lines) for four different neutralino annihilation compositions and the background (solid line) at solar minimum.

ucts;

- positrons will be measured in (1-300 GeV) with a mean acceptance of $0.045 \text{ m}^2 \cdot \text{sr}$ and a combined e^+/p rejection factor of $\sim 10^5$;
- gamma rays will be detected in conversion mode by measuring e^+e^- in the tracker and direct measurement in ECAL with no associated charged track activity;
- antiprotons will be measured in 0.5-200 GeV with a mean acceptance

of $0.03 \text{ m}^2 \cdot \text{sr}$ and a combined proton rejection factor of $\sim 10^6$;

- antideuteron production from proton-proton collisions is a rare process and it may be less rare in neutralinos annihilation. The present D/p ratio is about 10^{-5} .

The Fig.3 shows on upper left, the AMS02 model expectation for high accuracy antiproton flux compared with present data, on upper right, deBoer scenario (de Boer, 2004) with boost factor tuned to match HEAT+EGRET excess and AMS02 expectation, on lower left, integrated γ ray flux from neutralino annihilation as a function of m_χ . The considered models were *msugra* and Klaze-Klein Universal Extra dimensions (Jacholkowska et al., 2005). The results of the simulations in the framework of *msugra* model, show that with a cuspy dark matter halo profile or a clumpy halo, the annihilation γ ray signal would be detectable by AMS02 up to 1 TeV. In Fig. 3, lower right, the (Donato & Fornengo & Salati, 2000) model for χ annihilations at the galactic halo. At lower energies the \bar{D} the signal is well above background (solid line) at solar minimum.

4 Cosmic Ray Astrophysics

The primary and secondary cosmic ray measurements are essential to determine the backgrounds for weak signal searches. The present uncertainty on these fluxes is the main contributor for systematic errors on atmospheric neutrino oscillation calculations. In Fig 4 (Upper Left and Upper Right) are shown the present status for proton and helium fluxes and the expected AMS02 performance for after few hours of data collection.

Moreover, the study of relative abundances of elements and isotopes yields to a better understanding of origin, propagation, acceleration and confinement time of cosmic rays in our galaxy (Strong & Moskalenko, 2001).

The AMS02 mass resolution and charge determination capabilities and superconducting magnet provides very high sensitivity to determine the primary, secondary fluxes and heavy nuclei up to iron and for energies to few TeV.

The AMS02 will be able to measure the particle fluxes with high accuracy to $Z=25$ in the energy range 0.1 GeV/n - 1 TeV/n. In Fig.4 (Lower Left) the expected B/C ratio accuracy for 6 months of AMS02 data collection is shown together with model expectation (solid line) and most recent measurements.

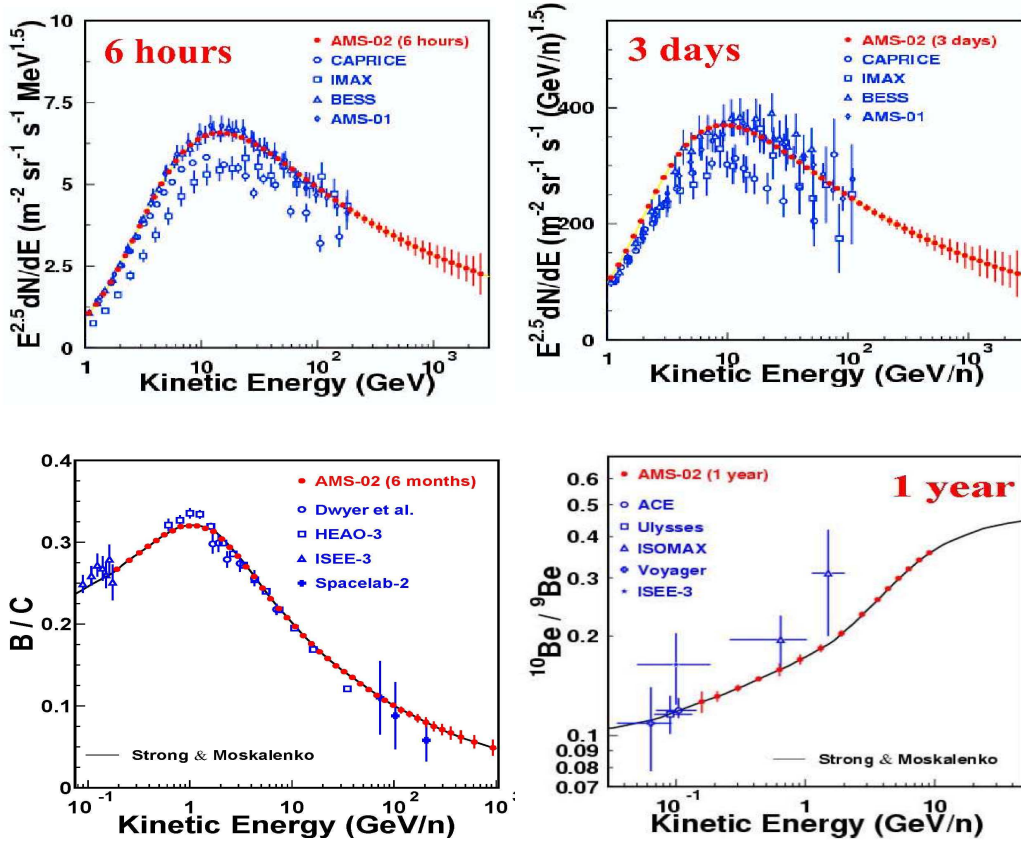


Figure 4: The present data and the accuracy expected by AMS02 for proton (UL), helium (UR), B/C ratio (LL) and $^{10}\text{Be}/^9\text{Be}$ ratio (LR) flux measurements.

The $^{10}\text{Be}/^9\text{Be}$ flux ratio with ^{10}Be being lightest unstable isotope with half-life comparable to the galactic confinement time of cosmic rays, will provide important hints on galactic halo height and on residence times of cosmic rays in our galaxy. In Fig 4. (Lower Right) shows high statistics measurement of $^{10}\text{Be}/^9\text{Be}$ flux ratio after one year.

5 Conclusions

The AMS02 has been designed to measure with ppb accuracy primary cosmic ray composition up to TeV region. These accurate measurements will allow better understanding of propagation and confinement mechanisms in our galaxy. The study of rare components will allow to search of new phenomena (dark matter, strangelets (Madsen & Larsen, 2003)) or to better constrain

the fundamental issues as the existence of primordial antimatter.

6 Acknowledgements

I wish to thank the organizers for their kind invitation to this stimulating and well organized Workshop.

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